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WATER RESOURCES AND COMMUNITY DYNAMICS IN THE AGA-FOUA-DJILAS WATERSHED, SENEGAL LOCAL PERCEPTIONS AND LOWLAND MANAGEMENT CHALLENGES

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ABSTRACT

Managing water resources in the lowlands of watersheds is crucial, especially in the context of climate variability and change. This article explores the challenges and opportunities associated with water management in the lowlands of the Aga-Foua-Djilas watershed in Senegal. The study examines people's perceptions of water resources, hydro agricultural structures, the relationship between water resources and production activities, the impacts of climate change on the water cycle, and people's expectations for sustainable water resource management. The study combines analysis of secondary data and community surveys. The results show that 82.7% of the population surveyed consider water resources to be scarce, and 47.4% consider hydro-agricultural structures to be very useful. Agriculture (market gardening 69.5%; rice growing 21.6%) and livestock farming (76.3%) are the main activities practiced. These activities have an impact on water quality and quantity. In addition, over 80% of the population expect technical and financial support, the construction of hydro-agricultural structures, the creation of village committees, the demarcation of livestock grazing areas, and their involvement in choosing the location of hydro-agricultural structures. These expectations are crucial for sustainable and efficient watershed management. Involving communities in the planning and execution of water projects enables beneficiaries to take ownership of the initiatives, strengthening their resilience to climatic fluctuations. Climate change has a profound impact on the water cycle in the watershed and directly influences various activities in the lowlands, requiring the sustainable use of water resources for a variety of purposes. These results underline the need for authorities to support integrated and sustainable water management in watersheds sensitive to climate change.

Keywords: Water resources, Community dynamics, Lowlands, Watershed, Aga-Foua-Djilas, Senegal

INTRODUCTION

Water resource management in the lowlands of African watersheds is a crucial issue in the face of the challenges imposed by climate variability and change (Lalika and., 2015; Nakou et al., 2023; Aroua, 2023; Qureshi et al., 2024; Mah et al., 2024). Lowlands, areas of topographic depression where water naturally accumulates, play a vital role in the hydrological cycle by regulating river flows, recharging water tables and supporting local ecosystems and agricultural activities (Pierce and al., 2012; Singo, 2018; Zegait and Pizzo, 2023). However, these regions are particularly vulnerable to climate fluctuations, which can exacerbate flood or drought risks, affecting water availability and quality (Benkhaled et al., 2013; Aroua, 2020; Nassa et al., 2021; Hafnaoui et al., 2022; Hafnaoui et al., 2023; Gassi and Saoudi, 2023).

Water, even sometimes floods, and other watershed resources are exploited for development and livelihoods (Remini, 2022; Long et al., 2023). However, most watersheds are vulnerable to the effects of climate variability and change, population growth and land use change (Remini, 2020; Adhikari and al., 2020; Chadee et al., 2023; Benali Khodja and Ferdjouni, 2024). The impacts of climate change are reflected in an increase in the frequency and intensity of floods and droughts (Doumounia et al., 2020; Assemian et al., 2021; Abd Rahman et al., 2023; Pang and Tan, 2023, Remini, 2023; Ben Said et al., 2024). Combined with high population pressure, these impacts can be detrimental in the absence of coordinated land and water use planning. Sustainable management of natural resources in watersheds can be achieved by using hydrology as a key unifying factor (Gu and al., 2013).

The African continent is already exposed to frequent and intense climatic extremes. Climate projections suggest that these phenomena will become more severe and unpredictable, directly impacting water resources and rural livelihoods (Dube and al., 2016; IPCC, 2014). The Aga-Foua-Djilas watershed will indeed be marked over the course of the 21st century, and whatever the projection scenario, by rising temperatures and potential evapotranspiration, against falling precipitation, runoff potential and infiltration potential (Dione and al., 2023), but also by falling flows (Dione and al., 2024). In this context, Integrated Water Resources Management (IWRM) becomes an essential strategy to ensure sustainable water use, reduce community vulnerability and promote resilience to climate shocks (Falkenmark and Rockström, 2006; Benson and al., 2020; He, 2013).

The lowlands of African watersheds, due to their unique hydrological nature, offer both challenges and opportunities for efficient water management (Tang and Adesina, 2022). On the one hand, their ability to retain water can be used to mitigate the impacts of droughts and support irrigated agriculture (Rey and al., 2017). On the other, inadequate management of surface and groundwater can lead to soil degradation, crop losses and conflicts over water use (Lambin and Meyfroidt, 2011).

To address these challenges, it is crucial to understand the specific dynamics of inland valleys in the context of climatic variations and to develop adapted management strategies. This includes improving hydraulic infrastructure, promoting resilient

agricultural practices and building institutional and community capacity (Jayne and al., 2021; Srinivasa Rao and al., 2016; van der Zaag and Gupta, 2008).

In the context of sustainable water resource management, assessing people's empirical knowledge of water resources is of vital importance (Pahl-Wostl and al., 2011). It provides information on people's ideas about historical trends in water availability, seasonal fluctuations and the risk of shortages. Watershed populations' perceptions of lowland water are closely linked to rainfall abundance and determine their decisions on whether or not to engage in market gardening activities during the dry season. This local knowledge, the fruit of daily experience, deserves considerable consideration in water resource management policies, especially those relating to the construction of hydro-agricultural structures (Dan-Azumi, 2011). The latter are built by the State and its partners, some to retain as long as possible the water drained by the watershed's lowlands and lost to the Atlantic Ocean, despite climatic variability and climate change; and others to combat the salinization of rice fields (Dione, 2010). Such developments contribute to the regeneration of natural resources and the development of off-season activities, which could increase people's incomes, revitalize the countryside through a certain cereal or cash crop production, reduce people's dependence on food aid and combat rural exodus (Mbodji, 2008).

The Aga-Foua-Djilas watershed was chosen for this study because of its strategic location in the Sine-Saloum region, where lowlands are intensively used for agriculture and livestock farming. Competition for these areas, combined with the growing impact of climate change, makes concerted management of water resources a matter of urgency. Studying this watershed provides an opportunity to develop appropriate co-management strategies for sustainable and resilient use of local resources.

This article examines the challenges and opportunities associated with water management in the lowlands of the Aga-Foua-Djilas watershed. The perceptions of the watershed's populations regarding water resources are highlighted. The article is also based on an analysis of secondary data, in addition to a holistic approach taking into account all activities revolving around water resources through community surveys and local case studies. It examines people's expectations of lowland development, and makes recommendations for sustainable water management that takes account of current and future climatic constraints.

PRESENTATION OF THE STUDY AREA

The Aga-Foua-Djilas watershed straddles the Municipality of Malicounda, Sandiara, Sessene and Ngueniene (Mbour département), and Tattaguine, Loul Sessene and Djilas (Fatick département) (Fig. 1). It covers an area of 317.5 km². It is one of the sub-watersheds of the Sine Saloum, one of the largest hydrological basins in Senegal. Geographically, the Aga-Foua-Djilas stretches between latitudes 14°15'N and 14°25'N, and longitudes 16°37'W and 16°53'W. Topographically, its highest elevations are to the north and northwest, and range from 23 to 42 m, covering an area of 11.94%. These altitudes correspond to the plateaus, which are the highest areas of the topo-sequence. The

middle elevations (12 to 23 m) account for 56.76%, or more than half the total surface area of the watershed. They form the connecting slopes and are the transition zones between uplands and lowlands. They are located in the center of the basin. The lowest areas of the topo-sequence have altitudes ranging from -8 to 12 m and cover 31.30% of the watershed. They correspond to low-lying areas along the drainage network. They are more extensive in the south-eastern part of the watershed, particularly at the outlet. Climatically, the Aga-Foua-Djilas basin lies in the coastal North Sudanian domain and is influenced by the Canary Islands (Sagna, 2005). It is marked by two alternating seasons: a rainy season (July to September) and a dry season (October to June) (Diatta 2000; Dione 2010).

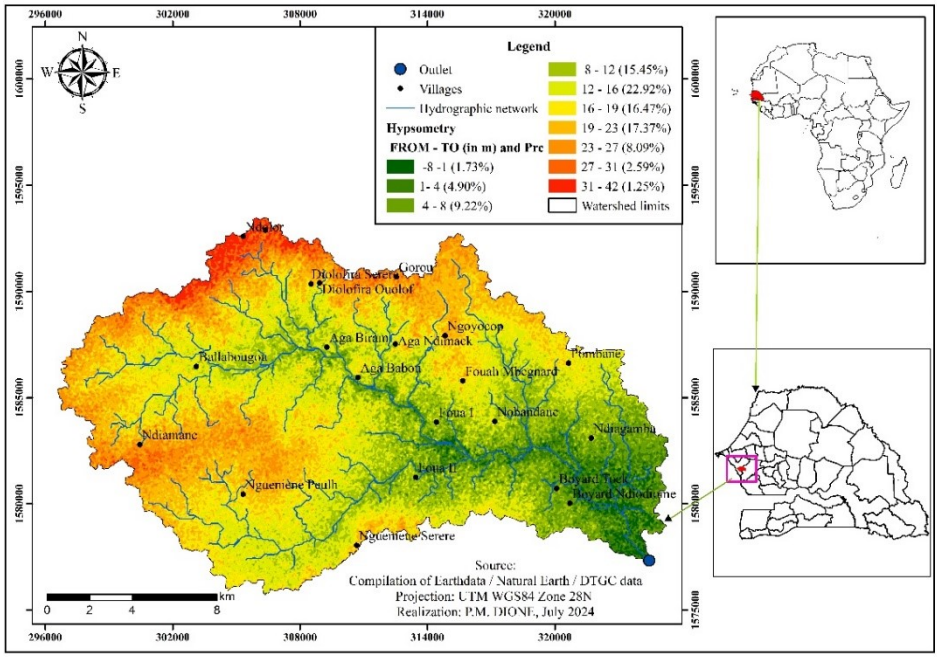

Figure 1: Presentation of the Aga-Foua-Djilas watershed

MATERIAL AND METHODS

The methodology used in the study was a combination of desk research, fieldwork and data analysis. Fieldwork included the use of questionnaires and interview guides to gather information on activities practiced in the lowlands, the relationship between water resources and production activities, people's perceptions of water resources and hydro-agricultural structures, water resource management organizations, and prospects for lowland development. Of the 21 villages in the watershed, surveys were carried out in 10, i.e. 47.7% of the total number of villages. The selection of villages was based on proximity to the main watercourse, the effectiveness of activities in the lowlands during

the dry and rainy seasons, and the presence of hydro-agricultural structures. The choice of villages was validated after defining a 2km buffer zone from the main watercourse using QGIS 3.26.3. Five zones were defined: zone 1, with villages located more than 8 km from the main watercourse; zone 2, with villages located between 6 and 8 km; zone 3, with villages located more than 4 to 6 km from the main watercourse; zone 4, with villages located between 2 and 4 km from the main watercourse; and zone 5, with the nearest villages located less than 2 km from the main watercourse. The villages in zones 4 and 5 have been selected. They are located exclusively in the Municipality of Ngueniene and Loul Sessene (Fig. 2).

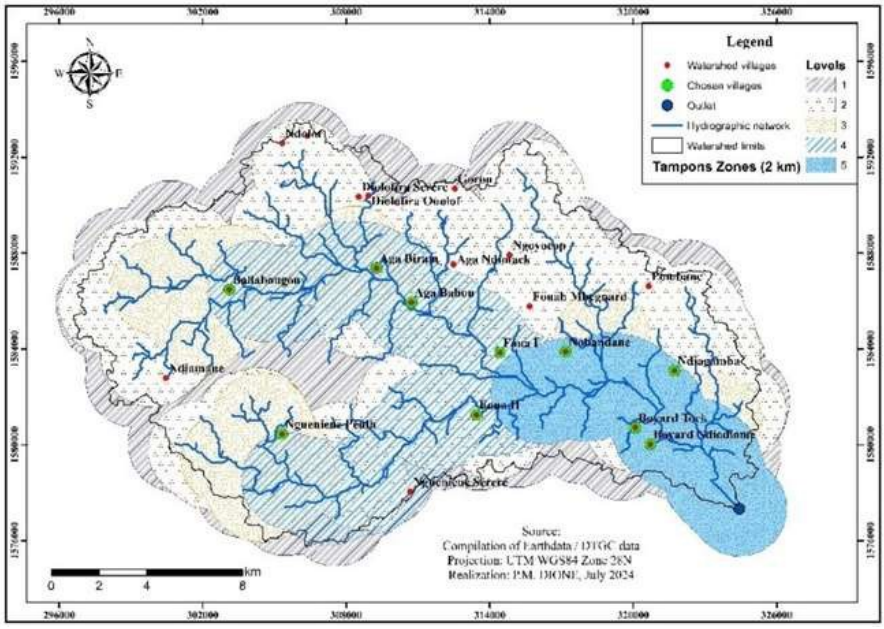

Figure 2: Buffer zones and villages surveyed.

Sample size was determined using Bernoulli's sampling formula (Eq. 1), as described in Lefebvre 2004.:

$$n = \frac{(Z)^2 \times N}{(Z)^2 + \alpha^2 \times (N-1)} \quad (1)$$

With n being the sample size; N, the size of the parent population; α, the width of the range expressing the margin of error (this range is equal to 2 times the chosen margin of error); Z, the standard value corresponding to the chosen confidence level.

For this study, the parent population (N) is 1414 households. The confidence level chosen was 95%. A total of 302 households were surveyed, distributed among the villages selected using the quota method. Quota sampling, also known as stratified sampling, involves dividing a heterogeneous population into sub-groups, or strata. The number of units for each stratum is proportional to the overall population

(https://www150.statcan.gc.ca/n1/edu/power-pouvoir/ch13/nonprob/5214898-fra.htm, consulted on 09/28/2024. The following formula (Eq. 2) is applied to determine the quota per village:

$$Village\ quota = \frac{Number\ of\ village\ households \times 302}{Total\ number\ of\ households\ in\ the\ 10\ villages} \quad (2)$$

Quotas by village are shown in Table 1.

Table 1: Quotas by village

Municipality	Villages	Number of households	Sampling	Percentages
LOUL-SESSENE	BOYARD NDIODIOME	175	37	12.4
LOUL-SESSENE	BOYARD TOCK	80	17	5.7
LOUL-SESSENE	NDIAGAMBA	221	47	15.6
LOUL-SESSENE	NOBANDANE	160	34	11.3
NGUENIENE	AGA BABOU	131	28	9.3
NGUENIENE	AGA BIRAME	77	16	5.4
NGUENIENE	BALLABOUGOU	192	41	13.6
NGUENIENE	FOUA I	173	37	12.2
NGUENIENE	FOUA II	106	23	7.5
NGUENIENE	NGUENIENE PEUL	99	21	7.0
	Total	1 414	302	100

Interviews were conducted between April and June 2023. Overall, the sampling method aimed to ensure good coverage of the catchment area and to guarantee the representativeness of the targeted villages. Random sampling was used to select the households to be interviewed, guaranteeing equal chances for all households in the village to be included in the study.

This Bernoulli method is one for simple random sampling and is widely used in various disciplines to estimate proportions and prevalences (Luo, 2024; Newman, 2022; Vul and al., 2014). Its simplicity, fairness and ability to provide representative estimates make it a valuable tool for researchers and practitioners alike.

RESULTS

Perception of the population on water resources

The availability of water resources in the lowlands is assessed differently, as shown in Fig. 3. 82.7% consider water resources to be not very abundant and 16.9% consider them to be abundant. Only 0.3% consider them to be very abundant. These predominantly unfavorable perceptions underline the importance of implementing sustainable water resource management and conservation solutions in this vulnerable region.

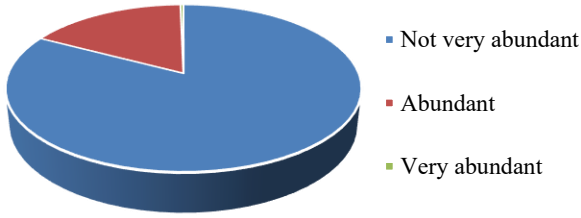

Figure 3: People's perception of lowland water resources (Source: Survey results, 2023)

The abundance or otherwise of water resources in the lowlands is one of the determining factors in their drying out. Drying up is considered very early by 52.2% of farmers surveyed. 33.2% considered it to be early, and 14.6% thought it was late (Fig. 4). Drying up is perceived as a major obstacle to agricultural and pastoral activities.

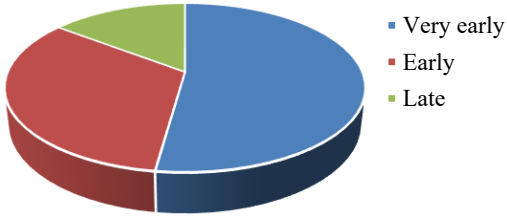

Figure 4: Assessments of the drying up of lowlands (Source: Survey results, 2023)

The early drying-up of the lowlands is the result of a combination of factors. According to the people interviewed, this drying-up is due to a combination of rainfall deficit, silting-up of the lowlands, winds and other factors such as sunshine, overexploitation linked to multiple uses, notably livestock watering and market gardening (Fig. 5).

All farmers point to rainfall deficits as the primary cause of the early drying-up of the lowlands. Falling rainfall reduces the volume of water available for storage. This situation is exacerbated by the silting-up of the lowlands, mentioned by 87.6% of respondents. Sediments from upland areas drained into lowlands by erosive agents such as wind and runoff reduce their water storage capacity. At the same time, this can lead to problems of

inadequate drainage, changing the texture of lowland soils and influencing their fertility. Wind, for its part, affects evaporation, causing lowlands to lose water. Through its speed, vertical structure and turbulence, it plays a major role in the evaporation process. 45.6% say it is a determining factor in the availability of water resources in the lowlands.

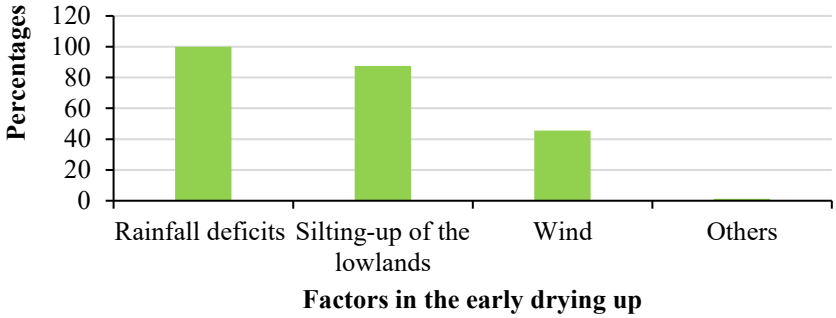

Figure 5: Factors in the early drying up of lowlands (Source: Survey results, 2023)

Hydro-agricultural developments

Hydro-agricultural developments in the watershed include anti-salt dams and water retention dams downstream, and retention basins upstream. In addition, bridges facilitating the movement of people and goods have been built on certain roads. Fig. 6 shows the location of these structures.

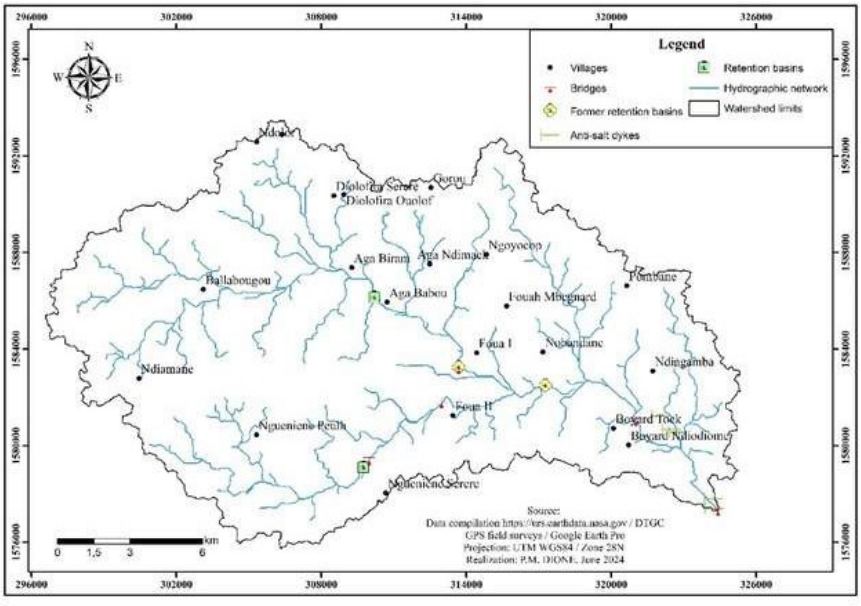

Figure 6: Location of hydro agricultural facilities and bridges

Anti-salt dikes

The Aga-Foua-Djilas watershed is subject to saline intrusion at its outlet. Located in a low-lying area, it is therefore vulnerable to sea-level rise and flooding, as are other regions (Sahu and Mehta, 2024). This saline intrusion can affect the quality of available fresh water and impact agricultural activities in the watershed, hence the importance of anti-salt dykes.

A total of 5 anti-salt dykes have been built in the watershed. Their purpose is to protect rice fields from salinization (Albergel et al., 1992), but also to retain water in rice-growing plots for as long as possible to enable the rice to complete its cycle (PAPIL, 2006).

The first dikes date back to colonial times. Lacking maintenance, they fell into disrepair and collapsed over time. In 2004, the National Hydrographic Network (RHN), via SENAGROSOL, which became iDEV Engineering Consulting on August 1, 2009, built a dike at the « Fambara » lowland. Not far from this dam, two others were built in 2007 by the Small-scale local irrigation support project (PAPIL). These are the « Okhakh » and « Kasnokhokh » dikes (Fig. 6).

The other two dikes were built at the basin outlet at the « Farondole » lowland. The first, the smaller, was built in 2010 by the Ministry of the Environment to the south-west of the village of Dack. Given its length (80 m) compared to the width of the lowland, it was unable to hold back the water, and part of it was destroyed by the rains of the 2010 rainy season (Dione, 2010). The issue of salt leaching was far from resolved, which did not guarantee a resumption of rice-growing activities. This failure probably justifies the construction in 2019 of the largest dikes, the « Farondole », by the Agricultural Sectors Support Project (PAFA), which was financed by the International Fund for Agricultural Development (IFAD), the OPEC Fund for International Development (OFID), the Global Environment Facility (GEF) and the State of Senegal. To avoid the shortcomings of previous developments, a longer dike was built perpendicular to the first. In fact, it is the longest of the dikes. It extends over 1165 m and is built in a low-lying area that forms the outlet of two watersheds: the Aga-Foua-Djilas basin, which is the focus of this study, and the Ndiol Khokhane-Djilas basin. The latter extends from the village of Ndiol Khokhane to the northeast of Djilas, at the same outlet as the Aga-Foua-Djilas basin.

Photo 1 shows the situation of the « Fambara » and « Farondole » dikes in the dry season (April 2023), as well as during the rainy season (September 2023).

Photo 1: Dikes of « Fambara » and « Farondole » in the dry and rainy seasons

Retention basins

Two retention basins are currently operational in the watershed. These are the retention basins in the villages of Ngueniene Peul and Aga Babou, built in 2004 by the Retention Basins and Artificial Lakes Department (DBRLA). These basins have an agropastoral function. Every year, a significant quantity of rainwater is lost to the Atlantic Ocean. The ponds reduce this loss by retaining much of the run-off water.

At Foua 2, a retention basin was built at the same time as those at Aga Babou and Ngueniene Peul. However, the basin collapsed around 2016-2017 due to several factors. According to some farmers interviewed, the length of the retention basin was small and it was constantly bypassed by runoff. In addition, during the rainy season, it caused flooding of adjoining fields, which had a negative impact on production. Those affected would not hesitate to come at night, using sticks and hammers, to cut holes in it to release the water that was invading their fields. This aggression weakened the retention basin, which eventually gave way in the face of heavy rains.

In Nobandane, a retention basin was also built in 2009 by the NGO World Vision. Heavy rains during the 2010 rainy season caused the basin to give way to run-off water. It was rebuilt, but failed again in 2011 for the same reasons (Dione, 2011).

A:Ngueniene Peul retention basin in April 2023. | B:Aga Babou retention basin in April 2023.

Photo, DIONE, P. M., 2023

Photo 2: Ngueniene Peul and Aga Babou retention basins in the dry season

Photo 2 shows the dry-season status of the Ngueniene Peul and Aga Babou retention basins. It can be seen that the Aga Babou reservoir, built in the « Aga onde » lowland until April 2023, is still retaining water from the 2022 rainy season, visible in the right background of the photo, unlike the Ngueniene Peul reservoir, which dried up earlier.

These various cases of structures collapsing following heavy rains point to a number of development shortcomings, not least the problem of controlling the hydrological parameters required to size the structures, but also their location. The Ngueniene Peul retention basin is built upstream of the area's largest and deepest lowland. This limits its capacity to retain more water and partly explains its early drying-up. The Aga Babou dam, on the other hand, is located downstream of the large lowland. As a result, it holds more water and dries up later (Photo 2).

The perception of the population on hydro-agricultural developments

Local people who use the facilities have different opinions on their usefulness (Fig. 7). 47.4% consider the structures to be very useful, 43.6% think they are useful. 5.3% said they were of no use at all, and 3.8% said they were of little use.

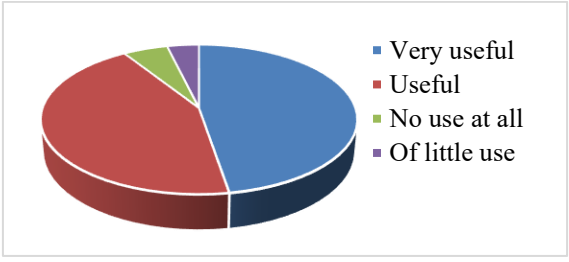

Figure 7: Perception of the population on the structures (Source: Survey results, 2023)

At village level, although there is a wide disparity in opinions, Graph 9 shows that the majority of respondents are satisfied with the structures. With the exception of Boyard Ndiodiome, where 91.9% consider the dikes to be very useful, the perception that the facilities are useful dominates in the other villages (Aga Babou: 42.9%, Ngueniene Peul: 85.7%, Ndiagamba: 54.3%, Boyard Tock: 41.2%). This is followed in these villages by the view that the facilities are very useful (Aga Babou: 32.1%, Ngueniene Peul: 9.5%, Ndiagamba: 37.1%, Boyard Tock: 29.4%). Those who consider the facilities to be of no use at all are 10.7% in Aga Babou, 4.8% in Ngueniene Peul, 5.7% in Ndiagamba and 2.7% in Boyard Ndiodiome. In Boyard Tock, none of the respondents said the dikes were useless (Fig. 8).

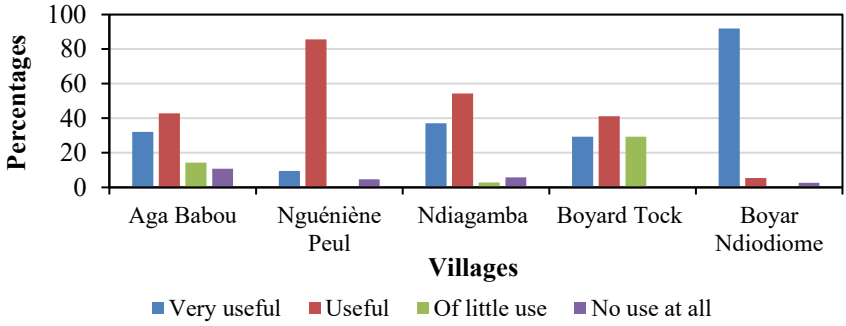

Figure 8: Perception of the population on the structures according to the villages (Source: Survey results, 2023)

In Aga Babou, those who consider the retention basin useless are market gardeners who once farmed the land in the lowlands. Now that the retention basin has extended the water's stay in the lowlands, they are deprived of their market gardening plots and are struggling to find plots of land to develop. In the cases of Boyard Ndiodiome and Ndiagamba, women rice growers feel that their ancestral land has been taken away from them and given to others who feel that the dikes are of no use.

The involvement of the population in the implementation of hydro-agricultural developments

One of the aims of hydro-agricultural schemes is to enable the population to use water resources to boost their activities. Consequently, these developments must be within the reach of users, enabling them to achieve greater water efficiency. In order to succeed in such a challenge, the involvement of the stakeholders concerned is very important. It enables us to identify the uses and users, and the aspirations of each category. What's more, the empirical knowledge of local populations can help to make better choices for the location of structures, over and above technical topographical, pluviometric and hydrological studies. Involving the local population can bring new, innovative ideas adapted to local needs, and new, more sustainable approaches.

Water management also means ensuring the long-term viability of the works carried out, through monitoring and control. This is a fundamental aspect of efficient, sustainable agriculture. The extent to which local people take ownership of the facilities depends to a large extent on their degree of involvement. Indeed, in addition to physical data, integrated water management strategies must involve local people through their strategies, know-how, usage patterns, representation systems and culture, their logic, but also their search for solutions to the problems experienced (Mendy, 2014).

The land issue is also an important aspect to take into account prior to construction, especially as the sites on which the facilities are built are owned or operated by different families. Other logics are taking shape, and recompositions and restructurings are required. This fundamentally alters the way the valley or lowland is used, and calls into question the land tenure, social and economic equilibrium of the land thus modified (Gilardoni and al., 2017). This state of affairs can give rise to the risk of land disputes. To avoid all the likely disagreements, risks and disputes, it is therefore important to create a consultation framework upstream, with the aim of defining the rules of governance that will be democratic, participatory and inclusive.

When asked whether the local population had been involved in the development process, the answers varied from village to village. 5 of the 10 villages surveyed have developed anti-salt dams (Boyard Tock, Boyard Ndiodiome, Ndiagamba, which share the same facilities) and retention basins (Aga Babou and Ngueniene Peul). Fig. 9 shows the different responses provided on a global scale. 54.3% of people surveyed in villages with facilities said that the population was involved in the process, while 15.2% said the opposite. The remaining 30.4% said they didn't know whether or not the population was involved.

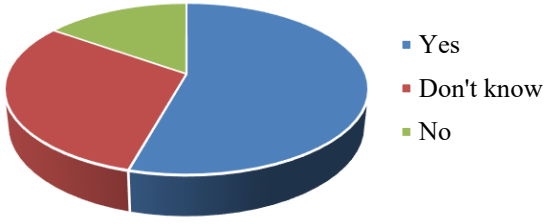

Figure 9: Involvement of the population in the process of carrying out hydro agricultural developments (Source: Survey results, 2023)

At village level, the situation is different, as shown in Figure 10. In Aga Babou and Ngueniene Peul, villages in the commune of Ngueniene, the population was not at all involved in the process. No response was given to any case of involvement.

In Aga Babou, 71.4% of respondents said the population was not involved, and 28.6% said they didn't know (Fig. 10). « People came to build the retention basin and left when the work was finished. Apart from the local workforce recruited (guards), no form of collaboration was noted. After the work was finished, no one else came back, not the

President of the Rural Community, nor the Sub-Prefect » (This argument was put forward by an Aga Babou market gardener.) This attitude poses a serious problem in terms of local ownership of the project.

The case of Ngueniene Peul is somewhat unusual. The retention basin lies between the villages of Ngueniene Peul and Serere. This is reflected in the assessment of local involvement. 95.2% of villagers surveyed said they didn't know whether the local population had been involved or not, and 4.8% maintained that they had not.

In the other villages, although more than half of those surveyed acknowledged that the local population had been involved, the situation was different. In Boyard Ndiodiome, the highest proportion of respondents (97.3%) acknowledged that the local population had been involved. This can be explained by the fact that this is the village where the works management committee is headquartered, and from which the late chairman of the committee originated. What's more, it's the village closest to the developed sites.

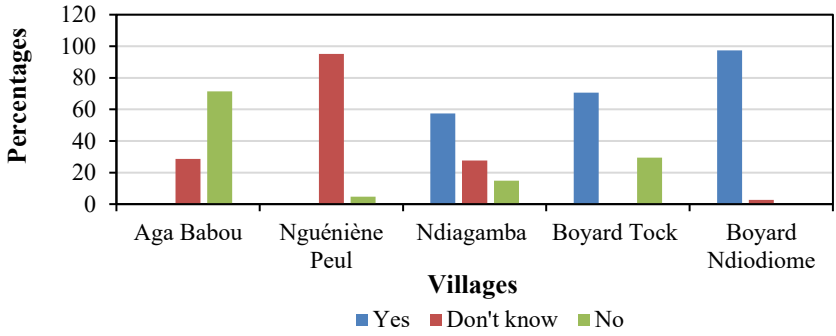

Figure 10: Involvement of local people in the hydro-agricultural development process, by village (Source: Survey results, 2023)

Village water resources management organizations

Apart from the Inter-village Valley Management Committee (CIVG) « MBIND-JAM » (the house where peace reigns), there are no other water management or hydro-agricultural development structures in the watershed. This inter-village committee brings together committees from the villages of Ndiagamba, Boyard Tock, Boyard Ndiodiome and Dack. However, the committee is encountering enormous difficulties that are hampering its smooth operation. In Aga Babou, on the other hand, there is no formal structure, but the inhabitants, particularly the farmers working around the retention basin, meet most often, pay their dues and buy cement to repair the cracks and other dilapidations of the structure. They do, however, notify the village chief and city councilors in their capacity as local authorities. Such a voluntary initiative can be undertaken by anyone. The commune of Ngueniene also has an association of market gardeners. It helps its members acquire inputs and market their produce.

Water resources and production activities

Relationship between water and production activities

The main economic activities in the Aga-Foua-Djilas basin are livestock farming (76.3%), market gardening (69.5%) and rice growing (21.6%) (Fig. 11). These agropastoral production activities depend on a variety of water sources, including surface water in the lowlands, groundwater from village wells and « ceanes » wells, and water stored in retention basins and dykes. Other non-agricultural activities are also practised. These include angling and domestic uses such as washing clothes and dishes. The productivity of these various activities is closely linked to the availability and diversity of water resources in the watershed.

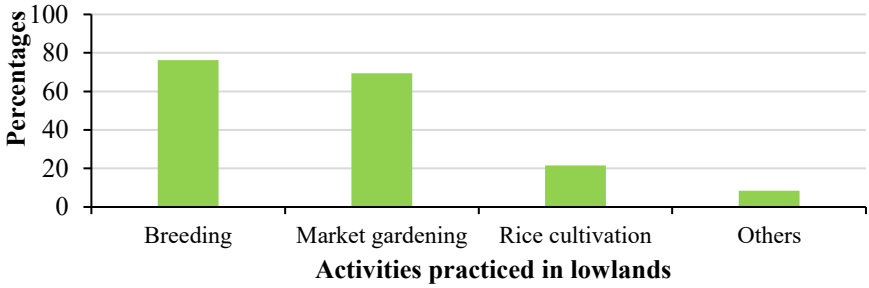

Figure 11: The different activities practiced in the lowlands of the watershed (Source: Survey results, 2023)

The relationships between the different types of water resources and the sectoral uses made of them by the populations of the basin are presented in the Table 2. The latter shows the importance of surface water, which is heavily used by both farmers and livestock farmers to meet their needs.

Table 2: Relationships between types of water resources and sectoral water uses (Faye, 2013, adapted)

Types of water	Uses
Surface waters: - The slums; - Retention basins; - Anti-salt dikes and reservoirs.	Market gardening (irrigation); Arboriculture (irrigation); Watering of livestock; Artisanal angling; Domestic uses (washing clothes).
Rainwater	Rain-fed agriculture; Domestic uses (washing clothes).
Groundwater - Village well; - « Ceanes » well; - Wells equipped with motor pumps; - Wells equipped with solar pumps.	Gardening; Watering of livestock; Drinking water supply; Domestic uses (washing clothes).

Impact of uses on water resources

There are many uses of water in the catchment area: herders use it to water their livestock, farmers carry out rainfall activities as well as off-season, women use it to wash clothes and supply households with drinking water, fishing is practiced by a few men, young and old. Due to the very large number of potential uses for a catchment area with a temporary flow, the study of the Aga-Foua-Djilas usages, is complex. The competing sectors, as well as the level of satisfaction and the pressures exerted on the water resources of the watershed are identified from the analysis of uses (Table 3).
Between uses, different relationships appear. They depend on the nature of the action exerted on the resources and the spatiotemporal dimensions of the use. The strong interactions between uses are highlighted by the actions associated with each use. Indeed, in the Aga-Foua-Djilas basin, each use involves one or more actions on the water resource: (Dione, 2010 and field surveys 2023)

Off-season market gardening, watering livestock, washing clothes involve sampling actions;

- The use of phytosanitary products for plant care promotes the discharge of toxic products that pollute surface and groundwater and soil;
- The development of retention basins and anti-salt dikes and reservoirs creates an artificialization of the natural voices of the hydrographic network;
- Sand quarries dug in the shallows promote the creation of water retention points that are used for the same activities as the shallows.

Table 3: Actions on water resources, satisfaction levels and the main constraints on water use (Faye, 2013, adapted)

Uses and users (functionality or service)	Actions on water resources and their impact	Level of satisfaction with water resources		Constraints limiting user satisfaction
		Quantity	Quality	
Domestic uses (drinking water supply, laundry)	Surface water and groundwater (drinking) samples; Direct discharge and degradation of aquatic environments.	Good availability in flood periods; Some water shortages in the basin, especially in times of drought.	Watersheds that meet standards despite certain levels of pollution.	Sanitation limited by the capacities of the receiving environment.
Agriculture (rain-fed, market gardening, arboriculture); Breeding;	Abstraction of surface water and groundwater (watering of livestock, washing, irrigation); Diffuse landfills (spreading) and soil transformation; Degradation of aquatic environments (wetlands, etc.).		Good and satisfactory overall.	Terrestrial pressure in areas close to the river.

Vegetation (logging)	Changes in the second-round regime.	-------	-------	Deforestation
Fishing	Derivation; Degradation of aquatic environments.	Unsatisfactory use.	Poor quality due to pollution (domestic water discharges); Premature drying of the lowlands.	All economical uses.
Aquatic environment (wetlands)	Local resource; Self-purification, flood mitigation; Self-management of sediments; Biological diversity.	Disappearance of wetlands; Fragmentation and reduction of wetlands.	Landing of wetlands; Standardization of wetlands.	Land pressure, land use impacts.

Impacts of climate change on the water cycle

Climate change has profound impacts on the water cycle (Table 4), which directly affects many socio-economic activities. Beyond the rapid melting of the snowpack of the North and South Poles and the associated rise in sea level; It has led to changes in rainfall patterns in almost all regions of the world. This, in turn, affects water supply and demand. The main effects of climate change are documented in the Table 4:

Table 4: Impacts of climate change and population growth on the water cycle in the watershed (Sources: 2023 field surveys; CSE, 2020; Dieng, 2017; (Faye, 2016; Papil, 2013)

Climate variability	Impacts on the water cycle
- Variability of precipitation; - Decrease in rainfall; - Disruption of the wet season calendar; - Increased variability of rainfall and extreme events; **- Rising temperatures;** - **Increased evapotranspiration;** **- Sea level rise;** - Saline intrusions in the estuary (outlet of the basin); - Progression of the salt wedge in the aquifers of the estuary (outlet of the basin).	**- Increase in levies;** **- Decrease in water resources;** - Reduced flow rates; - Loss of predictability of water availability; - Decrease in groundwater recharge; **- Reduction of the magnitude of the annual flood;** - Reduction of water retention in wetlands; **- Degradation of water quality;** - Salinization of estuary resources (basin outlet); **Marine submersions** (basin outlet).

Prospects for the development and management of water resources and the expectations of the population

Livestock, market gardening and rice cultivation are the main activities practiced in the lowlands of the Aga-Foua-Djilas watershed. The sustainable use of water resources by the various actors, according to the uses, would require that the expectations of the concerned be taken into account. This not only facilitates social acceptance, but also ensures that development projects are adapted to local needs. Indeed, from a sustainable development perspective, it is « important, (...) to involve all actors at the level of the defined geographical functional unit and to integrate economic, social and environmental components in order to move in a clear and unanimous direction. Collaboration brings better coordination and also improves future planning and management » (https://gire.ch/definition/definition-de-gire/, accessed March 13, 2024). In addition, in a Sahelian country like Senegal, where quality water resources tend to be scarce due to the continuous deterioration of the climate since the 1960s, in addition to being constantly solicited, for the sake of sustainable development, their rational and equitable exploitation must therefore be done. (Dgpre, 2021)

As the main users of the water resources of the watershed, the local populations have expressed their desire for the sustainable development of their activities. Those expectations revolve around (Fig. 12):

- **Technical and financial support (97.7%**): not having access to financing and using obsolete and rudimentary means, they would like to be supported in this regard;
- **The construction of structures (95.3%**): the population wants to see an increase in hydro-agricultural developments, retention basins as well as anti-salt dikes and water reservoirs in order to retain water all year round and fight against the salinization of the land;
- **The establishment of village committees (95.3%):** these committees will bring together all the users of water resources. They will be in charge of managing the developments, mobilizing, organizing and supporting the actors. They will also be the intermediaries between the populations and the State, as well as the partners;
- **The training of stakeholders (88%**): among the constraints of development is the lack of training and mastery of processing techniques, especially among market gardeners. Training in cultivation and product processing techniques will help to optimize and increase yields;
- **The delimitation of cattle grazing (84.6%**): the lowlands are used by breeders to water their livestock. The practice of agricultural activities in these areas is at the origin of several conflicts related to the wandering of livestock. For a sustainable cohabitation of the two activities, the cattle grazing must be delimited in order to allow the livestock to access the watering places without constraints;
- **The involvement of the population in the choice of the location of the structures (84.3%**): the inhabitants of the villages have in-depth experience in the field. Their involvement can help to better plan development policies and facilitate the appropriation of the structures. This involvement makes it possible to identify needs and expectations, and to avoid certain socio-economic blockages. Some of the

shallows in the basin have a mystical connotation and are considered to be places inhabited by spirits, who in traditional religions are sometimes benefactors or evildoers (Dione, 2010)

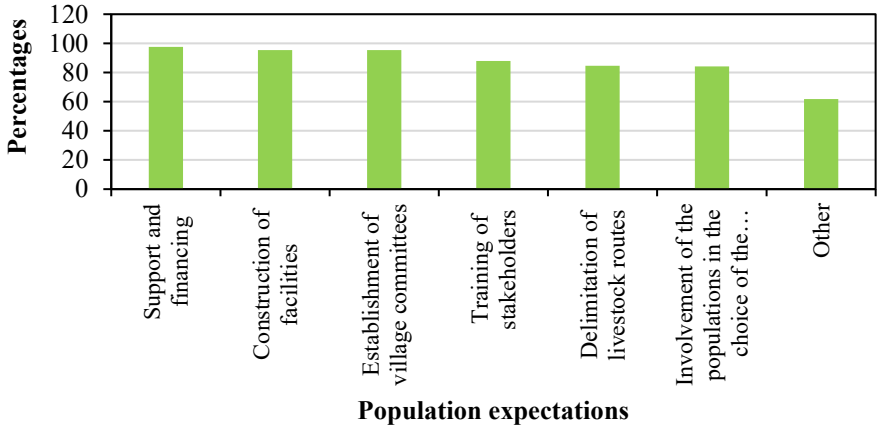

Figure 12: Expectations of the population for the sustainable exploitation of water resources (Source: Survey results, 2023)

Other expectations are raised by the population. This involves dredging the length and breadth of the shallows, which are heavily silted. Moreover, this silting up is considered by 87.6% of respondents to be responsible for the early drying up of the lowlands. In addition, the sustainability of activities also depends on the control of other constraints that hinder the development of activities around and in the lowlands.

DISCUSSION

The results of this study highlight the challenges and opportunities associated with water resource management in lowland watersheds in Africa, in a context of climate variability and change. Several salient points emerge from the analysis of data and field observations.

The various activities carried out in the lowlands have a considerable impact on water resources, which are strongly affected by climate change. Rising temperatures and rainfall anomalies are leading to longer periods of drought and more frequent flooding (Shaikh and al., 2022). These phenomena disrupt the seasonal availability of water, directly affecting agricultural activities and the food security of local populations (Dube and al., 2016; IPCC, 2014).

With climate variability and change, water is at the heart of adaptation and resilience strategies for the populations of the Aga-Foua-Djilas watershed. Its availability determines the development of agropastoral activities in the watershed. People's assessment of the resource reflects its poor availability. 82.7% of households consider water resources to be not very abundant, and 52.2% describe the drying-up of lowlands

as very early. Ponds dry up just after the rainy season. Yanon et Ndiaye (2013) note this early drying-up in the Bambey area (central Senegal). This decline, observed by the local population through their daily experience, corroborates the results of HMF-WA model simulation of basin flows over the historical period (1981-2019), by Dione and al. (2024).

To ensure sustainable development of the lowlands and rational management of the basin's water resources, the local population formulated a number of expectations, notably the construction of hydro-agricultural structures (95.3%), their involvement in choosing the location of these structures (84.3%), and the setting up of village committees (95.3%). The involvement of local populations, the beneficiaries of the developments, is indeed important, insofar as they have a better understanding of socio-cultural realities. It's an approach that enables people to take ownership of the developments. Non-appropriation can encourage the abandonment of works after the departure of partners and results from a lack of structuring among farmers, their low or non-involvement in the process of identifying and developing the project adapted to their needs, and the absence of transfer of skills and know-how for the continuation of activities (Mendy, 2014).

These expectations also show that IWRM is a promising approach for improving the resilience of hydrological and agricultural systems. It promotes coordination between different stakeholders and efficient use of available resources (Srinivasa Rao and al., 2016; van der Zaag and Gupta, 2008). Community initiatives, such as local water management committees, play a key role in implementing these strategies.

Climate projections predict a decline in rainfall (Dione and al., 2023) and flow (Dione and al., 2024) throughout the 21st century in the watershed. In addition, their combination with land use changes has an impact on hydrological systems, as shown by similar studies. However, for an effective study of trends, it is essential to combine local and global climate data in order to develop more robust adaptation policies (Chadee et al., 2023). In order to continue agropastoral activities and ensure food security in the basin, local populations need a sustainable management approach based on system dynamics and their expectations, rather than a linear approach. The realization of these expectations could be achieved after a diagnostic study to identify community challenges and find a strong consensus around the exploitation of terroir resources.

For an in-depth diagnostic study of the watershed, remote sensing offers many possibilities, including the control of geophysical parameters (Mehta et al., 2022), the provision of information on land cover and runoff dynamics (Mehta et al., 2023), and the monitoring of land surface temperature changes, essential for water cycle monitoring (Sharma et al., 2023). In the same vein, hydrological modeling with advanced models such as ANFIS (Adaptive Neuro-Fuzzy Inference System) offers promising avenues for accurate precipitation and runoff forecasting (Kantharia et al., 2024).

CONCLUSION

This study has revealed the multiple potential of the lowlands of the Aga-Foua-Djilas basin, where agricultural activities (notably market gardening at 69.5% and rice growing at 21.6%) and livestock farming (76.3%) dominate the local economy, in addition to domestic uses and fishing. However, the vulnerability of these activities to climatic hazards (droughts, floods) exacerbates the difficulties of managing water resources, which are essential for maintaining agricultural yields and food security.

The results show that local populations have valuable empirical knowledge of water management, but they express an urgent need for support to preserve hydro-agricultural structures, guarantee effective water retention and combat the salinization of arable land. With this in mind, the establishment of village water management committees, including all users, is crucial for a participative co-management that perpetuates activities and strengthens local resilience.

Finally, to ensure proactive and sustainable management, it is essential to strengthen climate monitoring and educate communities on adaptation strategies. This study proposes clear recommendations: development of adapted infrastructures, promotion of resilient agricultural practices and strengthening collaboration between governments, NGOs and local communities. These measures, part of an integrated approach, provide a roadmap towards sustainable and resilient development, capable of ensuring water and food security in this climate-sensitive region.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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